# A Reverberation Chamber for Animal Exposure at Millimeter Waves

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## SHORT ABSTRACT

A mode stirred reverberation chamber (RC) is designed to conduct *in vivo* studies in the 60-GHz band. This exposure system has suitable features for experiments on animals. An interface, for temperature measurements using an infrared (IR) camera, is designed in the chamber wall in order to measure the specific absorption rate and/or the power density inside the chamber.

## INTRODUCTION

Many applications at millimetre waves (MMW) have emerged recently: security body scanners operating around 30 GHz in public areas, short-range wireless communication systems for next-generation high speed networks in the 57-64 GHz band [1], short range automotive radars (77 to 81 GHz) [2], 5G communication systems, etc. Furthermore, the deployment of these new applications has triggered questions about potential health effects. Part of the answer to these questions can be found through *in vivo* bioelectromagnetics studies.

In the last decade, mode-stirred reverberation chambers (RC) have been investigated and implemented for *in vivo* animal exposures [3-6], but only at radiofrequencies (wifi signal: 2450 MHz ; mobile-phone frequencies: 848.5 MHz, 900 MHz, 1900 MHz). RC-based exposure system allows to generate significant exposure level. The exposed animals can move freely inside the RC, stress level is reduced compared to other exposure systems (Ferris-Wheel, radial waveguide, etc.) where animals are restrained in a small volume. In addition, the exposed animals are immersed in a statistically isotropic and uniform field regardless of their position in the volume of the chamber.

In this study, a RC is designed for *in vivo* experiments with mice exposed in the 60-GHz band. The target power density ranges from 1 mW/cm$^2$ to 5 mW/cm$^2$, which are the restrictions for general public and occupational exposure respectively, for frequencies between 10 and 300 GHz, recommended by ICNIRP [7]. This exposure system has suitable features to conduct experiments on animals, the climatic conditions are monitored: lighting, temperature, ventilation and humidity.

## MATERIALS AND METHODS

### Application description

One of the applications for this RC is to carry out experimental studies to assess the welfare of animals. "SWISS" mice of 4 weeks old will be exposed at 60 GHz, at exposure levels of 0 (sham exposure) and 1 mW/cm$^2$. Semi-chronic exposition will be carried out in RC, 2 hours per day, 5 days per week during 4 weeks. The animals will be distributed into six groups composed of five mice each. Two groups will be exposed to 1mW/cm$^2$; two other groups will constitute the sham exposure control in the RC, and the two last ones will constitute the control-cage groups. To establish the degree of animal stress induced by exposure or by housing in RC, several parameters will be monitored: food intake, animal weight, coat condition, behaviour (exploration, aggressiveness) and corticosterone serum control.

## Exposure system

Figure 1 represents a 3D computer-aided design (CAD) view of the proposed RC with inner dimensions 580×592×595 $mm^3$. The chamber walls are made of aluminium with a thickness of 10 mm. Two WR-15 open-ended waveguides are used as transmitting and receiving antennas. A metallic mode stirrer connected to a DC motor rotates continuously to generate the random field in the volume. The exposure system is located in an animal laboratory, where all the room conditions are monitored: temperature between 20-24 °C; air humidity between 45-65% and air exchange 15-20 times per hour, light cycle and levels (130-325 lux). This reduces manufacturing issues related to the animal housing. Two low noise (31 dB) fans with air flow rate of 5 $m^3$ per hour are installed in the chamber walls to ensure the air exchange between the RC and the animal laboratory room. By taking into account the open area (65%) of the woven wire metal mesh used for the shielding, the air in the RC is renewed 16 times per hour. Thus, the climatic conditions in the RC are expected to be the same as inside the animal laboratory room. In order to get the suitable light level in the RC, 8 windows of 100 mm × 100 mm size are installed in the upper face of the RC. Glass diffusers with a transparency of about 70% are used to improve the uniformity of lighting in the RC.
Woven wire mesh is used for all interfaces to ensure electromagnetic shielding. It is made of aluminium with a wire diameter of 50 µm and the open area surface is about 65%, leading to a simulated level of -26 dB for the power transmittance coefficient at 60 GHz, using HFSS.

To perform thermal imaging measurements, using a FLIR SC5000 infrared (IR) camera, a specific interface is designed to ensure simultaneously a high transmittance at IR and shielding effectiveness in the 60-GHz band. To this end, we used a calcium fluoride ($CaF_2$) dielectric substrate coated with a highly reflecting conducting inductive mesh. The power transmission coefficient (90%) has been measured over a wide spectrum covering the IR camera spectral range, *i.e.* 2.5-5µm. A sample with aluminium mesh (period $a$ = 200 µm, metallization width $d$ = 5 µm and thickness $t$ = 2 µm) was fabricated on $CaF_2$ substrate by photolithography. The transmission coefficient measured in the 2.5-5 µm range varies between 82.6% and 81.5%.

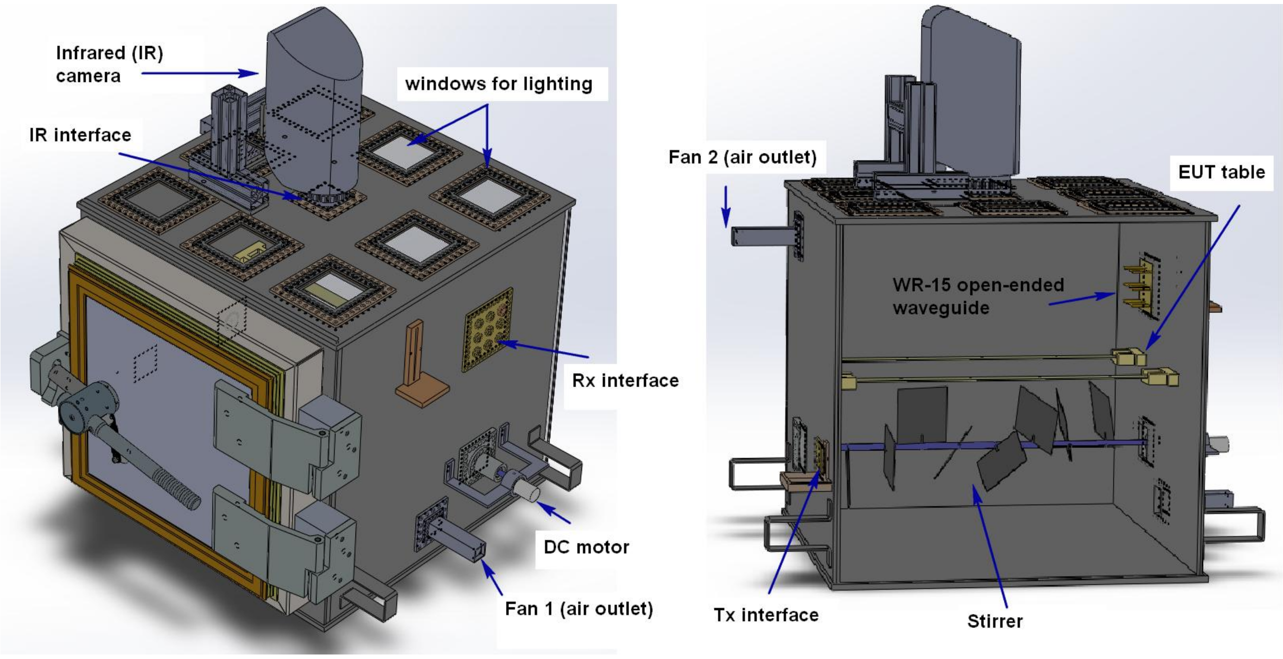


*Figure 1: 3D CAD view of the reverberation chamber designed with Solidworks*

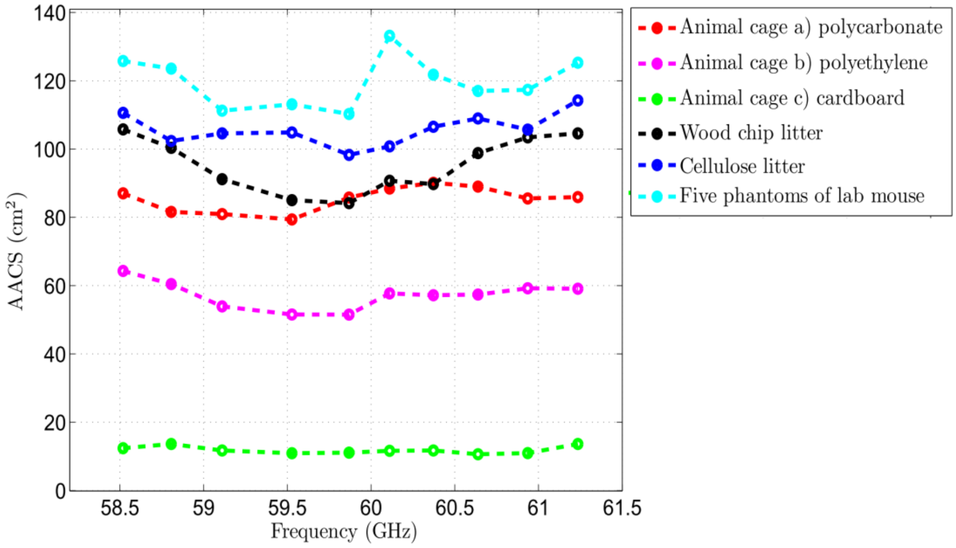


*Figure 2: The average absorption cross section (AACS) of conventional animal cages, bedding materials and five phantoms of lab mouse in the 58.5 - 61.5 GHz.*

Preliminaries studies were carried out in our pilot RC [8] in order to estimate the Q-factor and the maximum power density delivered by the exposure system. We demonstrated that the statistical behaviour of the experimental electromagnetic field inside this RC designed for operating in the 58.5–61.5-GHz range is consistent with that of a classical RC. The average absorption cross section (AACS) of three conventional mouse cages (polycarbonate; polyethylene; cardboard), two types of bedding material (wood chip litter, cellulose litter) and five mice phantoms, have been measured in the 58.5-61.5 GHz frequency range (see results in Figure 2). The animal cage with cardboard has the smallest losses compared to the other plastic cages. For the bedding material, the wood chip litter is slightly less absorbent than the cellulose litter. The composite Q-factor of the exposure system loaded with five phantoms of mouse, the cardboard animal cage and the wood chip litter can be predicted as [9]

$$\frac{1}{Q_{loaded}} = \frac{1}{Q_{empty}} + \sum_{i=1}^{N} \frac{1}{Q_i}, \qquad (1)$$

where $Q_{empty}$ and $Q_{i(i=1:N)}$ are the quality factor associated to the wall losses and the loading objects respectively, under the hypothesis of mutually independent objects

$$Q_{empty} = \frac{3 \times V}{2\mu_r S\delta}, \qquad (2)$$

$$Q_i = \frac{2\pi V}{\lambda \times AACS_i}. \qquad (3)$$

In equations (2-3), $V$ is the cavity volume, $S$ is the wall surface area, $\mu_r$ is the wall permeability, $\delta$ is the skin depth, $\lambda$ is the wavelength in free space and $AACS_i$ is the average absorption cross section of loading objects. The numerical value of $Q_{loaded}$ calculated in the 58.5-61.5 GHz frequency range is about $10^4$. The estimated Q value is sufficiently high compared to the threshold level of the quality factor results from the hypothesis that the electric field is Rayleigh distribution ($Q_{th} = 450$) [10]. Consequently the maximum average power density predicted for the exposure system is 8 mW/cm$^2$ for an input power of 2W.

## CONCLUSIONS

This study presents a reverberation chamber designed for conducting *in-vivo* experiments at millimeter wave frequencies. The estimated quality factor of the RC loaded with a group composed of five mouse phantoms, a conventional cage and the bedding litter is about $10^4$ at 60 GHz. The average power density expected for an input power of 2 W is about 8 mw/cm$^2$. The characterization of the exposure system will be detailed in the poster.


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